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A Novel Opportunistic Spectrum Sharing Scheme for Cognitive Ad Hoc Networks

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Abstract: Nowadays, wireless ad hoc networks are using a static spectrum allocation which leads to congestion in this spectrum parts as the number of devices increases. On the contrary, a significant portion of the spectrum in licensed band (e.g. TV band) is not utilized. Cognitive radio (CR) is a promising technology to solve the spectrum inefficiency problem in ad hoc networks. Based on CR, the unlicensed (secondary) users will utilize the unused spectrum of the licensed (primary) users in an opportunistic manner. As a result, the average spectrum usage will be increased. However, the sudden appearance of primary users will have a negative impact on the performance of secondary users, since secondary users must evacuate the occupied channel and handoff to another unutilized one. This process continues till an unlicensed user finishes his transmission. We will name this process consecutive spectrum handoff (CSH). In order to increase the performance of CR, the number of consecutive spectrum handoffs should be reduced. In this paper, a novel opportunistic spectrum sharing scheme under a heterogeneous spectrum environment of licensed and unlicensed bands is introduced. In this scheme, the licensed channels will be used as operating channels and the unlicensed channels will be used as backup channels when the primary user appears. Since the unlicensed channels are not interrupted by primary users, no more spectrum handoff is needed.

Keywords: Opportunistic spectrum sharing, Cognitive ad hoc networks

1 Introduction

As the number of wireless ad hoc devices in unlicensed band increases, the blocking probability for new devices is rising, since this band suffers from fixed spectrum allocation. On the contrary, the Federal Communication Committee (FCC) reports that 70 percent of the spectrum in licensed bands are not utilized [tec02]. Therefore, a new technology should be applied to make this free spectrum available and to reduce the capacity problems in the unlicensed band. Cognitive Radio (CR) [Mit00, MM99] is such a technology. It is expected to be a key component of future wireless ad hoc systems and will empower wireless devices with the capability of dynamically accessing the entire spectra. This goal can be realized only through dynamic and efficient spectrum management techniques.

CR technology is built on the software defined radio (SDR) technology which has been introduced as a key enabler for Dynamic Spectrum Allocation networks. Wireless devices with SDR

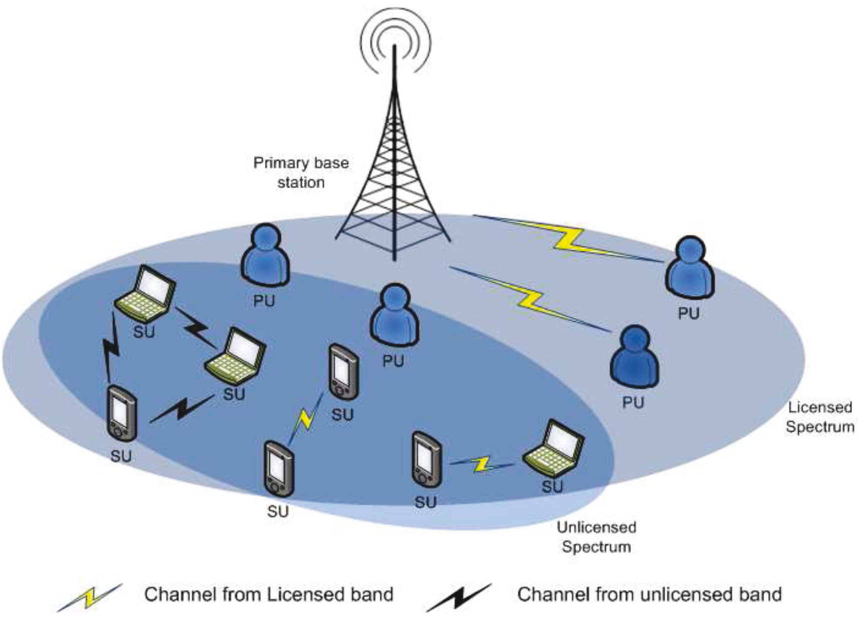

Figure 1: Ad hoc users co-exist with primaries

can rapidly reconf gure the operating parameters, such as frequency range, modulation type and maximum transmission power according to the surrounding environment. In Dynamic Spectrum Allocation networks, the secondary users (SUs) with SDR support can periodically search and determine unused channels in the spectrum. Based on the scan results, SUs can communicate with each other without interfering the primary users (PUs). Figure 1 shows a CR network scenario where ad hoc users co-exist with PUs. In this f gure, SUs operate in a mixed environment that consists of licensed and unlicensed bands. SUs operate in this heterogeneous environment without interference with PUs.

An interesting overview of CR and current challenges in this technology was introduced in [ALVM06, ALVM08]. Moreover, the CR network functions such as spectrum management, spectrum mobility and spectrum sharing are explained there in detail.

According to [ALVM06, Nex], SUs in (neXt Generation) xG networks can operate in both licensed and unlicensed bands. Despite a lot of research, two problems have not been addressed so far. First, most of the researchers are focusing on the behavior of SUs in the licensed band, supposing that the unlicensed band is already saturated and therefore the effect of unlicensed bands is neglected. Second, although the average spectrum usage will be increased when applying CR, the consecutive appearance of PUs on the performance of SUs is ignored. We believe that consecutive spectrum handoff (CSH) by SUs among different unoccupied spectra has a negative effect on the whole performance.

The contribution of this paper is two-fold.

- Increasing the spectrum capacity for ad hoc networks using CR technology.
- Reducing the number of CSH in case of the appearance of PUs

To achieve our goal, a new scheme for spectrum sharing under a heterogeneous spectrum environment of licensed and unlicensed bands is introduced. We believe that most of the wireless devices in the future will have CR capabilities and only few devices will be wireless devices without CR support. Since the licensed bands cover a large geographical area and a signif cant portion of this spectrum is unused, we suppose that an SU will utilize the licensed bands as operating bands, leaving the whole unlicensed band as a backup in case of the appearance of PUs. Each SU will be assigned a backup channel based on its MAC address. Since the MAC address of each node is known for the other neighboring nodes, it is easy for a node to calculate the backup channel for its neighbors in a distributed manner. The advantages of using unlicensed channels as backup channels are: 1) the blocking or data transmission termination probability will be reduced in case of the appearance of PUs. 2) no CSH is needed anymore. 3) the unlicensed band will be left to the few number of wireless devices that have no CR capabilities and therefore an enhancement of the overall system capacity will be reached.

The rest of this paper is organized as follows: An overview about related work is presented in section 2. Spectrum handoff in CR is shown in section 3. The proposed scheme is introduced in section 4. Finally, conclusion is presented in section 5.

2 Related Work

In most of the existing spectrum sharing schemes in the literature [CWK07, CC07, HCWC08, KA08, LH08, MHS05, TDPC07], the authors assume that SUs use only a particular pool of licensed channels opportunistically when PUs are not present. In case of an appearance of PUs, the transmission of SUs will be blocked until another free licensed channel is found or it will be dropped if there are no available channels. In their schemes, they assume that unlicensed channels are saturated and any new communication should be directed to licensed channels. Therefore, the effect of unlicensed channels on the behavior of SUs is neglected by them.

Spectrum sharing in CR networks can be regarded to be similar to multi-channel medium access control in existing wireless systems with some modif cation. Generally, multi-channel MAC protocols are classif ed [MSW08] in:

1. Dedicated Control Channel: where one dedicated channel is used to transmit control messages. This channel should be monitored by all nodes and should be available most of the time [CWK07, CC07, HCWC08, LH08, MHS05, TDPC07].

2. Common Hopping: where all nodes hop between all channels using a predef ned pattern. When both, source and destination, exchange control messages successfully, they stop hopping and start transmitting the data. After f nishing, they return back to the original hopping pattern.

3. Split Phase: where time is divided into phases such as control and data phases. During the control phase, all nodes switch to the control channel and decide which channel will be used for the upcoming data transfers. After a successful transmission of control messages, data transmission takes part during the data phase.

4. Multiple Rendezvous: where multiple nodes can exchange control information simultaneously on different channels. Each node knows in advance the hopping sequence of the other nodes. Therefore, exchanging control messages will be possible because the transmitter knows the hopping sequence of the intended receiver.

As can be seen from the classif cation, most of the MAC protocols proposed in the literature do belong to the dedicated control channel class and so does our proposed scheme. However, our envision is different from the above schemes in the way how the available spectrum pool will be managed. We assume that each node has a spectrum pool from different bands. The licensed band will be used as the operating band in case of the absence of PUs and the unlicensed band will be used as backup band in case of the appearance of PUs. If all the licensed band channels are occupied, all additional transmissions will be switched to one of the free unlicensed band channels. If all channels are occupied, any further transmission will be blocked. As we mentioned before, CSH is one of the main negative impacts on the performance of SUs and therefore eff cient spectrum handoff scheme should be introduced. The next section presents an overview about spectrum handoff and different possible types of it.

3 Spectrum Handoff

In CR networks, spectrum handoff arises when the PU appears. In this situation, the SU has to suspend his transmission and move to another free channel. This process continues consecutively each time a PU appears. This is called CSH as mentioned before. This process is a challenge in CR technology and a new scheme is needed to reduce its negative impact. Different schemes may be used by an SU to complete the rest of its data transmission. In this section, two existing schemes will be introduced followed by our proposed scheme.

3.1 No spectrum handoff

In this scheme, an SU will stop its transmission because of the appearance of a PU on the operating channel. The SU will resume its transmission as soon as the PU f nishes its transmission. This process will continue until the SU f nishes its transmission. The disadvantage of this strategy is the wasted time until the PU f nishes his transmission.

3.2 Spectrum handoff to another free spectrum hole

In this scheme, an SU will switch to another free hole in the licensed band in case of the appearance of a PU in the operating channel. This process will continue till the SU f nishes its transmission. The disadvantage of this strategy is the increased transmission time for an SU caused by CSH. Furthermore, the load in the spectrum increases due to only partly f nished transmission of packets.

3.3 Spectrum handoff to a backup channel

This scheme is applied here in this paper. Here, an SU will switch to a backup channel from the unlicensed band in case of the appearance of a PU on the operating channel, since unlicensed bands are primary free bands.. The advantage of this strategy is that there are no CSH anymore and per transmission the number of spectrum handoff will be reduced to one handoff only.

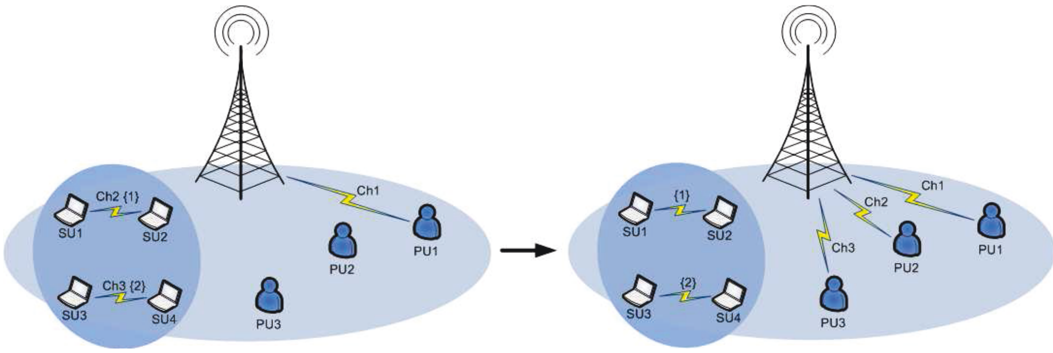

Figure 2: Example for cognitive ad hoc network

4 Opportunistic Spectrum Sharing Scheme

In this paper, we increase the system capacity for ad hoc networks using the CR technology. A simple but eff cient spectrum sharing scheme. Based on the proposed scheme, ad hoc users will operate and communicate under a heterogeneous spectrum environment of licensed and unlicensed bands. Since it covers a large geographical area and a signif cant portion of the spectrum is not utilized, the licensed bands will be used as operating channels. This reduces the load in the unlicensed band. Furthermore, the unlicensed band is a band without primary users which can trigger a spectrum handoff. Therefore, the unlicensed bands channels will be used as backup channels which limits the number of spectrum handoff per transmission to one. For example, Figure 2 supposes a network of three primary users ($PU1$, $PU2$, $PU3$) and four secondary users ($SU1$, $SU2$, $SU3$, $SU4$). The PUs and SUs operate over three licensed channels named ($Ch1$, $Ch2$, $Ch3$) and there are two channels (1 and 2) used by SUs as backup channels in case of the appearance of PUs. Since Ch2 and Ch3 are not utilized by PU2 and PU3, they will be used as operating channels for SUs. In case of the appearance of PU2 and PU3, the SUs will switch immediately to backup channels 1 and 2. The detailed description of the proposed scheme will be described in the next section.

4.1 The proposed scheme

In this section, an overview of the proposed scheme will be given. First, the operations of the proposed scheme is described. Secondly, we will discuss the advantages and disadvantages of the new scheme. Before that, the assumptions are summarized below.

- All nodes are assumed to be equipped with CR radios. If nodes without CR support should be included, they just lower the available bandwidth and increase the delay in the unlicensed band.

- There are two types of available spectrum, licensed and unlicensed spectrum.
- One of those channels will be selected as a common control channel for transmitting and receiving control messages.
- Licensed channels can be accessed by PUs and SUs on the basis that the SU may be preempted in case of the appearance of the PU.
- Every node is assumed to be equipped with two transceiver. One of the two transceiver is used for listening to the control messages and the other for both receiving and transmitting data.

During network initialization process, each node will predef ne a channel called backup channel from its free unlicensed channels. This will be achieved by using the following equation: Backup channel= MACaddress mod c_2, where c_2 is the number of unlicensed channels. Since the MAC address of neighbor node is known by the routing service, the neighboring nodes in the transmission range will calculate the backup channel for surrounding nodes in a distributed manner using the previous equation without the need to exchange further control messages or without extending existing protocols.

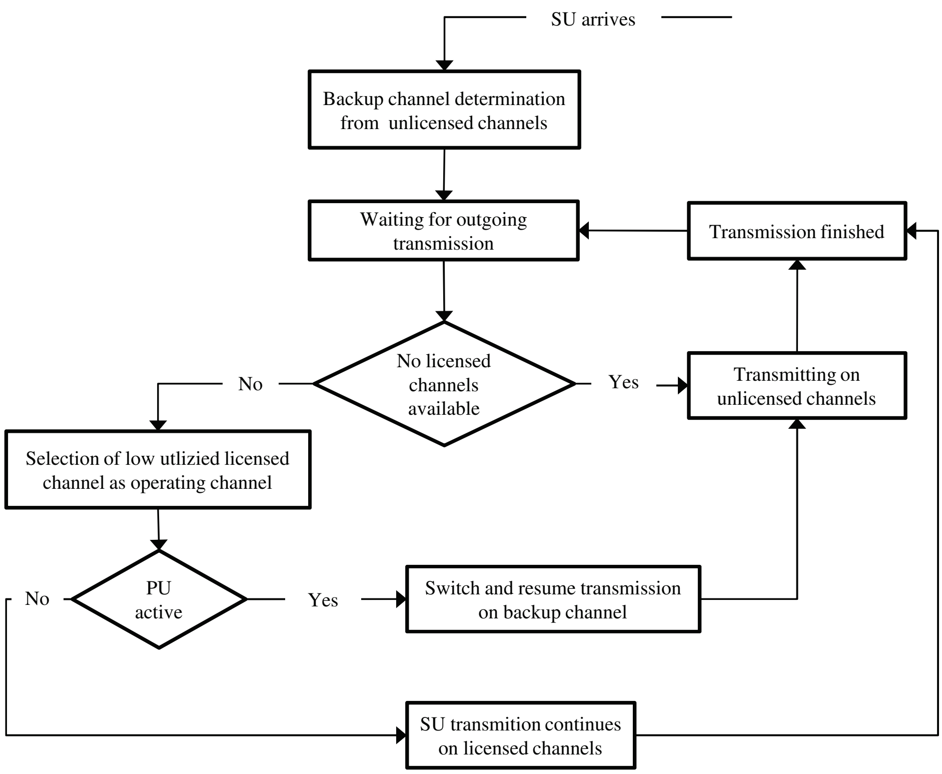

Figure 3: Flow chart for the proposed scheme

In this section the steps for the proposed scheme will be described as follows:

1. The sender will scan all available channels, this includes all channels from both licensed and unlicensed bands using its CR capabilities.

2. The backup channel will be selected from unlicensed channels according to the equation presented before.

3. The sender will sort the available licensed channels according to their utilization and the channel which has low utilization will be selected as operating channel.

4. The sender will send a Request To Send (RTS) control message via the common control channel. The message includes the operating channel.

5. Upon receiving the RTS, the receiver will check if this channel is available and therefore sends a Clear To Send (CTS) control message. If this channel is not available, no CTS will be sent.

6. Upon receiving the CTS, data transmission will begin on the operating channels.

7. The receiver knows in advance the backup channel for the sender (because the MAC address is known for all neighbors, it is easy to calculate the backup channel for each node). This channel will be used in case of the appearance of PU on the operating channel.

8. In case of the appearance of a PU, both sender and receiver will switch immediately to the backup channel and resume the transmission.

If there are no licensed channels available, SUs will transmit its data through the unlicensed channels as usual. The f ow chart of the proposed scheme is shown in Figure 3.

4.2 The advantage and disadvantage of the proposed scheme

The advantage using the proposed scheme are:

1. The system capacity will be increased.

2. The blocking and data termination probabilities will be reduced if the primary user appears.

3. The time needed for f nding a new channel for completing the transmission is minimized.

One drawback is the collision that may happen when SUs switch to a backup channel that is already occupied by other SUs or users without CR support. The backup channel may be occupied if :

- SUs neighbors have no cognitive capabilities and therefore they will use the unlicensed channels as operating channels (however, this has no effect since the main assumption of the proposed scheme is that all nodes are equipped with CR radios) or

- The number of SUs is greater than the unlicensed channels that will be used as a backup channels. Therefore, there is a probability that two SUs have the same backup channel.

5 Analysis and results

In this section, an evaluation of the proposed scheme will be given. Firstly, the basic assumption will be summarized. Secondly, the analytical model of the proposed scheme will be presented:

- The maximum numbers of licensed and unlicensed channels within the transmission range of a given node are assumed to be c_1 and c_2, respectively.
- The arrival process of PUs and SUs is assumed to be Poisson with rate λ_1 and λ_2, respectively.
- The call holding times of the PUs and SUs are assumed to be an exponential distribution with expectation $\frac{1}{\mu_1}$ and $\frac{1}{\mu 2}$ respectively

The states of the system is described by (i, j, k), where i is the number of licensed channels used by PUs, j is the number of remaining licensed channels; c_1-i used by the SUs and k is the number of unlicensed channels used by SUs as backup channels. The state (i, j, k) can be moved to another state depending on the arrival and the departure of PUs or SUs. For example, it can be moved to

- State $(i+1, j-1, k)$ because of the arrival of a PU. This case called complete preemption. This is done, because there is no available backup channels for SUs to complete his transmission (i.e. c_2=k).
- State $(i+1, j-1, k+1)$ because of the arrival of a PU. This case called preemption and handoff to backup channel. This is done, because there are available backup channels for SUs to complete data transmission (i.e. $0 < k < c_2$).

Let $P_1(t)$ be a random variable (RV), denoting the number of PUs occupying the primary channels at time t. Let $P_2(t)$ be a RV, denoting the number of SUs, occupying the primary channels at time t. Let $P_3(t)$ be a RV, denoting the number of SUs, occupying the secondary channels at time t. The process can be modeled as three-dimensional Markov process with state space $S = \{(i, j, k) \mid 0 \le i \le c_1, 0 \le j \le c_1 - i, 0 \le k \le c_2\}$. Let $p_{i,j,k,}(t)$ be the joint distribution of $P_1(t), P_2(t)$, and $P_3(t)$ and let $p_{i,j,k}$, be its limit.

Using the iterative technique, the all possible steady-state probabilities $p_{i,j,k}$ can be obtained. Once the probabilities $p_{i,j,k}$ are obtained, the blocking probability for SUs can be derived. An SU gets blocked if upon its arrival in a service area all the channels are occupied by either PU and/or SU. Thus, the blocking probability, P_b, can be written as follows:

$$P_b = \sum_{i=0}^{c_1} p_{i,c_1-i,c_2}$$

We used the previously derived equation to investigate the performance of SU while varying the value of primary channels c_1. The value of c_2 is set to 3 channels since the IEEE 802.11b standard supports three non-overlapping channels. If IEEE 802.11a standard is used, then c_2 will be set to 12 channels. The performance of the SUs is measured using different arrival and service rates. Firstly, we show the impact of the primary channels c_1 and the variation of the arrival rate

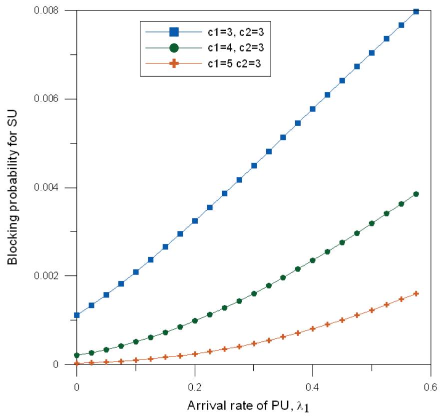

Figure 4: Blocking probability for secondary user vs. arrival rate λ_1

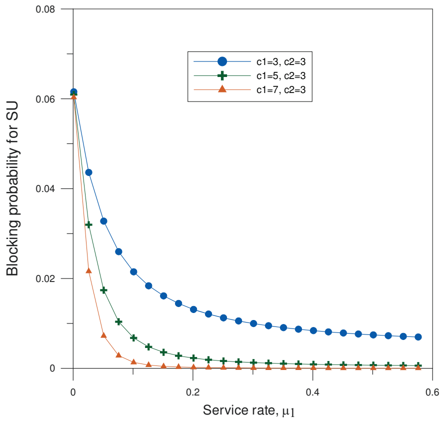

Figure 5: Blocking probability for secondary user vs. service rate μ_1

λ_1 on the blocking of the SUs. The following parameters have been used: $c_1 = 3,4,5$ and $0 < \lambda_1 \leq 0.6$, $\lambda_2 = 0.3$, $\mu_1 = 0.4$ and $\mu_2 = 0.4$. As shown in Figure 4, the blocking probability for SUs increase with respect to the arrival rate of PU λ_1. This can be explained as follows: As λ_1 increases and unchanged service time μ_1, the number of available channels that can be accessed opportunistically by the SUs reduces, which will lead to higher blocking probability for SUs.

Secondly, we show the effect of the variation of the service rate μ_1 on the blocking of the SUs. The following parameters have been used: $c_1 = 3,5,7$ and $0 < \mu_1 \leq 0.6$, $\mu_2 = 0.3$ and λ_2=0.3. It is obvious that when the service rate μ_1 increases, the channel holding time for PU will be decreased which leads to more primary channels being available. As a result, the blocking probability for SU will be decreased since the arrival rate of PU is fixed λ_1=0.2 as shown in Figure 5. Figure 6 depicts the blocking probability for SUs in a different spectrum environment. The figure shows that operating under heterogeneous environment of licensed and unlicensed channels will reduce the blocking probability of SUs.

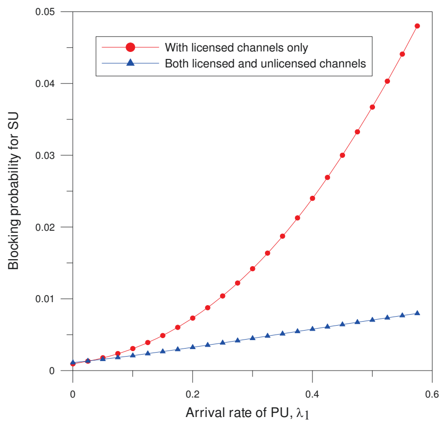

Figure 6: Blocking probability for secondary user with and without using licensed channels vs. arrival rate λ_1

6 Conclusion

In this paper, a novel spectrum sharing scheme for future ad hoc communications has been introduced. By applying this scheme, the blocking probability for SU will be reduced. Furthermore, the number of spectrum handoffs is reduced to one only. The main idea of the scheme is the usage of the licensed bands as operating band and the unlicensed bands are used as backup channels in case of the appearance of primary users. In future, other performance metrics like dropping probability and throughput will be derived. Also a validation for the analytical model will be done through a simulation.

Bibliography

[ALVM06] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, S. Mohanty. NeXt Generation/Dynamic Spectrum Access/Cognitive Radio Wireless Networks: A Survey. *Computer Networks Journal (Elsevier)* 50(13):2127–2159, September 2006.

[ALVM08] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, S. Mohanty. A survey on spectrum management in cognitive radio networks [cognitive radio communications and networks]. 46(4):40–48, April 2008.

[CC07] C. Cordeiro, K. Challapali. C-MAC: A Cognitive MAC Protocol for Multi-Channel Wireless Networks. In *Proc. 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2007)*. Pp. 147–157. 17-20 April 2007.

[CWK07] A. Chia-Chun Hsu, D. S. L. Weit, C. C. J. Kuo. A Cognitive MAC Protocol Using Statistical Channel Allocation for Wireless Ad-Hoc Networks. In *Proc. IEEE Wireless Communications and Networking Conference (WCNC 2007)*. Pp. 105–110. 11-15 March 2007.

[HCWC08] S.-Y. Hung, Y.-C. Cheng, E. H. K. Wu, G.-H. Chen. An Opportunistic Cognitive MAC Protocol for Coexistence with WLAN. In *Proc. IEEE International Conference on Communications (ICC 2008)*. Pp. 4059–4063. 19-23 May 2008.

[KA08] Y. R. Kondareddy, P. Agrawal. Synchronized MAC Protocol For Multi-Hop Cognitive Radio Networks. In *Proc. IEEE International Conference on Communications (ICC 2008)*. Pp. 3198–3202. 19-23 May 2008.

[LH08] L. Le, E. Hossain. OSA-MAC: A MAC Protocol for Opportunistic Spectrum Access in Cognitive Radio Networks. In *Proc. IEEE Wireless Communications and Networking Conference (WCNC 2008)*. Pp. 1426–1430. 31 March-3 April 2008.

[MHS05] L. Ma, X. Han, C.-C. Shen. Dynamic Open Spectrum Sharing for Wireless Ad Hoc Networks. In *Proc. IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005)*. Pp. 203–213. 8-11 November 2005.

[Mit00] J. Mitola. *Cognitive radio: An integrated agent architecture for software defined radio*. PhD thesis, Royal Inst. Technol. (KTH), Stockholm, Sweden, 2000.

[MM99] J. Mitola, J. Maguire, G. Q. Cognitive radio: making software radios more personal. *IEEE Personal Communications* 6(4):13–18, August 1999.

[MSW08] J. Mo, H.-S. So, J. Walrand. Comparison of Multi-Channel MAC Protocols. *IEEE Transactions on Mobile Computing* 7(1):50–65, Janaury 2008.

[Nex] The Next Generation Program. http://www.darpa.mil/sto/ smallunitops/ xg.html.

[TDPC07] M. Timmers, A. Dejonghe, L. van der Perre, F. Catthoor. A Distributed Multichannel MAC Protocol for Cognitive Radio Networks with Primary User Recognition. In *Proc. 2nd International Conference on Cognitive Radio Oriented Wireless Networks and Communications CrownCom 2007*. Pp. 216–223. 1-3 August 2007.

[tec02] Report of the spectrum efficiency working group. Technical report, Federal Communications Commission, November 2002.